New Paradigms for Remote Sensing and Monitoring of Microbial Ecosystems

Boulder CO January 9-10, 2008

Organizers:

Michael Mumma (Goddard)
Norman Pace (University of Colorado)
Mitchell Sogin (Marine Biological Laboratory)

Goal:

Explore experimental paradigms for the use of remote sensing of biosignatures to detect activities of microbial communities.

Current remote sensing technology for microbes:

Operates at 0.3 to 4 microns

Chlorophylls and other bacterial pigments

(Unambiguous signals with low information content)

Must expand the range of targets with greater information content

Establish a dialogue between remote sensing community

and

Microbial Ecologists and Biogeochemists.

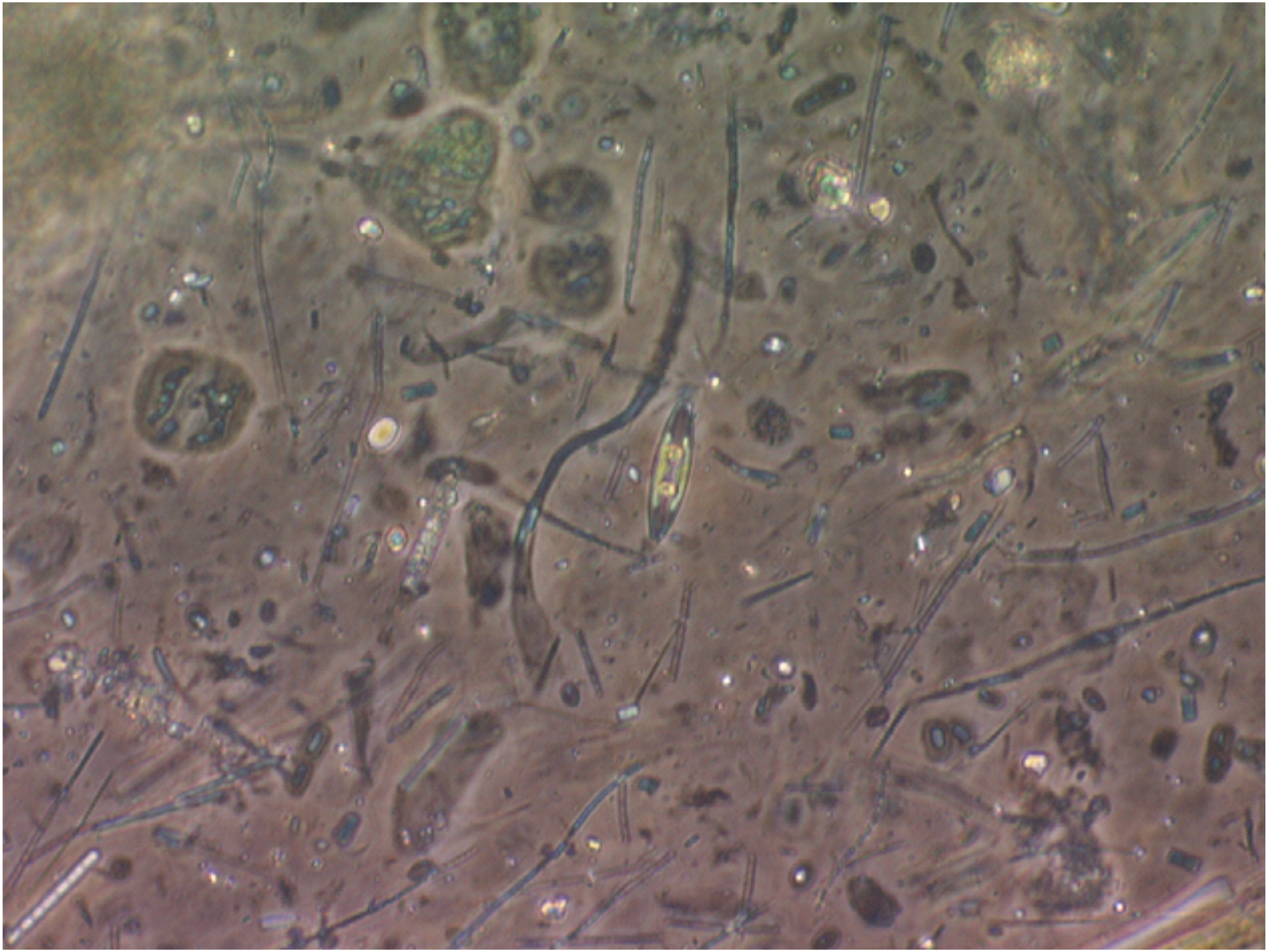
January 9th

8:45-9:00	Introductions	
9:00-9:15	Workshop objectives	Mitchell Sogin
	NAI Perspective	Carl Pilcher
9:15-9:45	Microbial Diversity and Population Structures	Norman Pace
9:45-10:15	Microbial Biosignatures	Tom Schmidt
		Dave Des Marais
10:15-10:45	Break	
10:45-11:15	Remote Sensing – Instrumental Capability	Mike Mumma
11:15-11:45	Rio Tinto: a case study of detecting signatures by remote sensing	Jack Mustard
12:00-1:00	Lunch -	
1:00-5:00	ad hoc presentations	
		Jim Abshire
		Kevin Hand
		Tori Hoehler
		Dennis Reuter
		Matthew Wallenstein

January 10th

8:00-8:30	Breakfast – Bugaboo A	
8:30-9:00	Summary of First day discussions	Mumma, Pace, Sogin
9:00-11:30	Experimental approaches Group discussion	
11:30-12:00	Lunch	
12:00 Departure.		

Organism



Endolithic Community in Sandstone

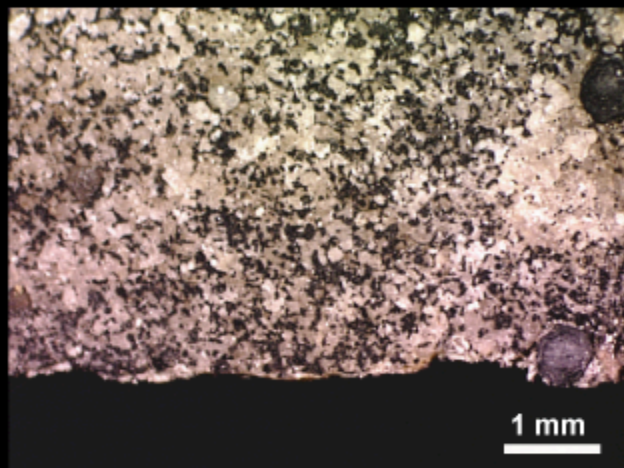


Fig 1. Exposed sandstone surface

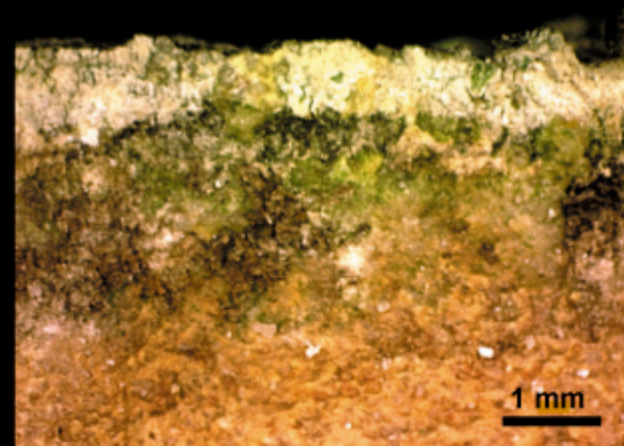


Fig 2. Cross section of sample in figure 1

Fig 3. 3D view

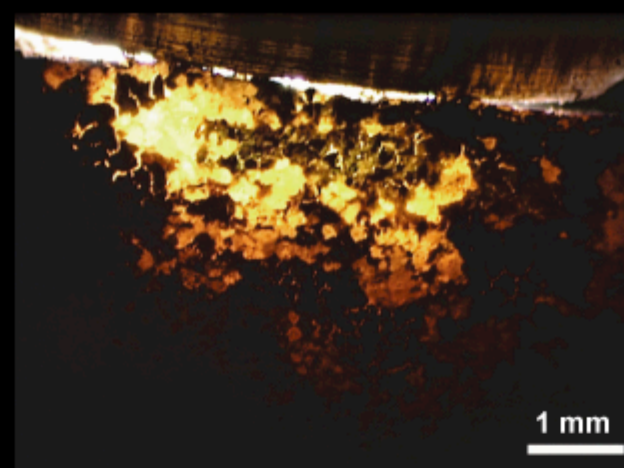
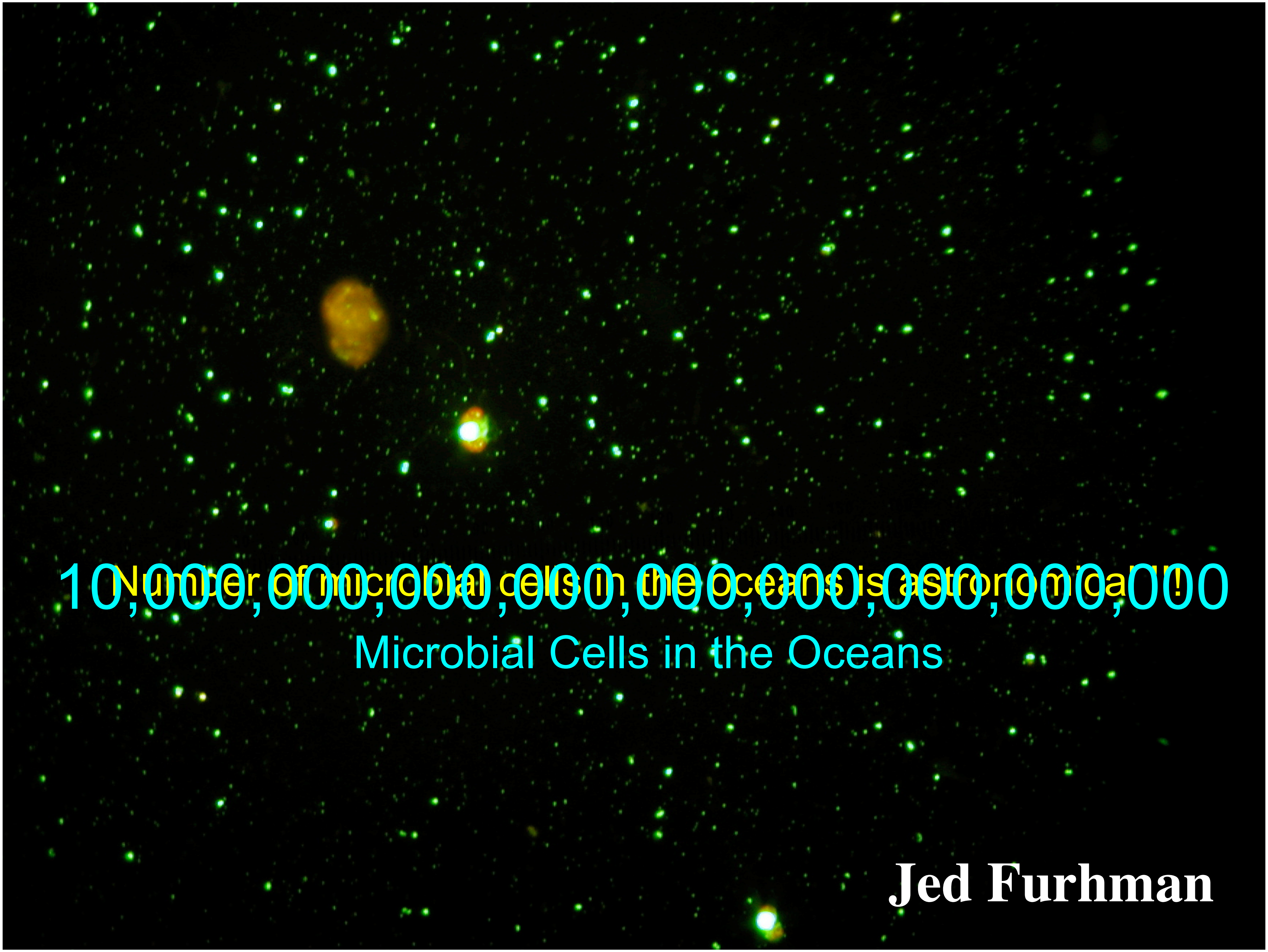
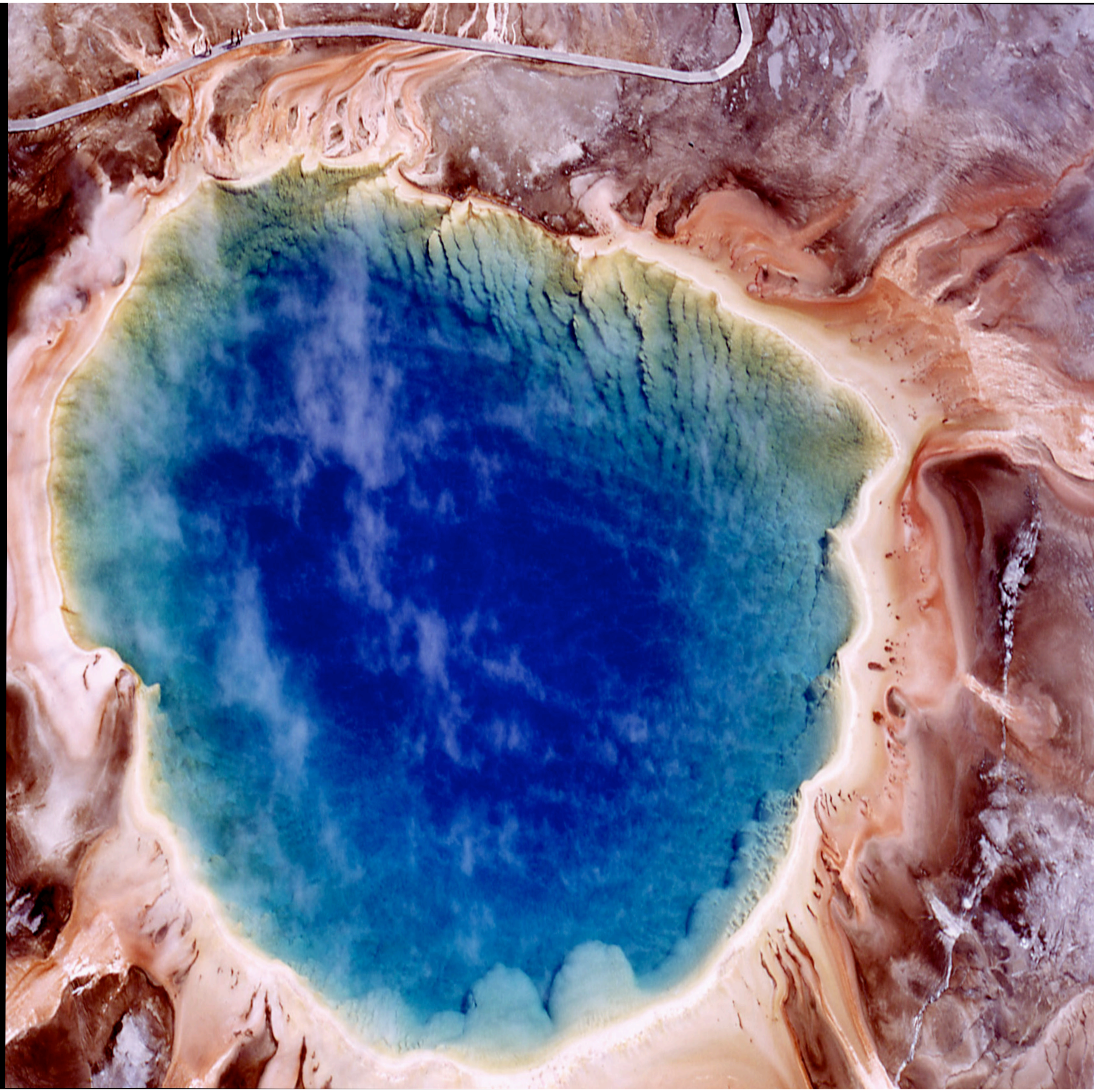


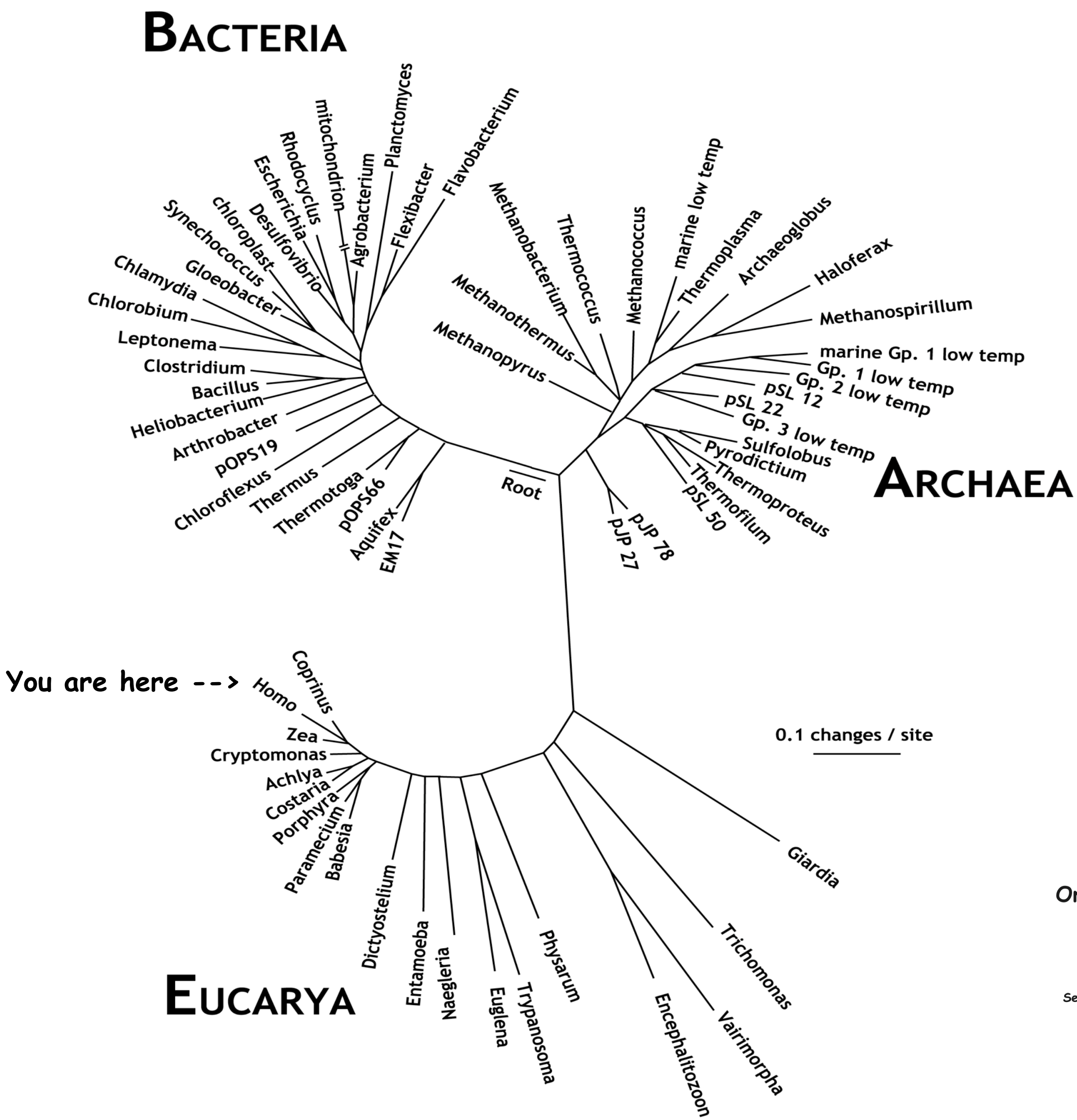
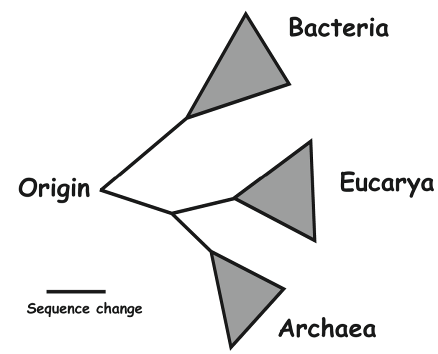
Fig 4. Same as figure 2, illuminated with fiber-optic light from the surface

Jeff Walker


Steve Giovannoni


10,000,000,000,000,000,000,000,000,000
Number of microbial cells in the oceans is astronomical !!!
Microbial Cells in the Oceans
Jed Furhman

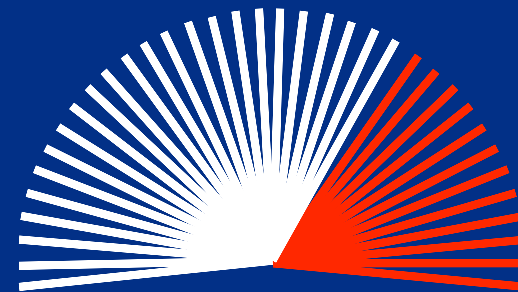



BACTERIA
Planctomyces
mitochondrion
Agrobacterium
Flavobacterium
Flexibacter
Rhodocyclus
Escherichia
Desulfovibrio
chloroplast
Synechococcus
Gloeobacter
Chlamydia
Chlorobium
Leptonema
Clostridium
Bacillus
Heliobacterium
Arthrobacter
pOPS19
Chloroflexus
Thermus
Thermotoga
pOPS66
Aquifex
EM17
Root
Methanobacterium
Thermococcus
Methanococcus
marine low temp
Thermoplasma
Archaeoglobus
Haloferax
Methanospirillum
Methanothermus
Methanopyrus
marine Gp. 1 low temp
Gp. 1 low temp
Gp. 2 low temp
pSL 12
pSL 22
Gp. 3 low temp
Sulfolobus
Pyrodictium
Thermoproteus
Thermofilum
pSL 50
pJP 78
pJP 27
ARCHAEA
You are here -->
Coprinus
Homo
Zea
Cryptomonas
Achlya
Costaria
Porphyra
Paramecium
Babesia
Dictyostelium
Entamoeba
Naegleria
Euglena
Trypanosoma
Physarum
Encephalitozoon
Vairimorpha
Trichomonas
Giardia
0.1 changes / site
EUCARYA

Bacteria
Origin
Eucarya
Archaea
Sequence change

Molecular Microbial Diverity

1987

12 divisions: 12 cultured/ 0 candidate



1997

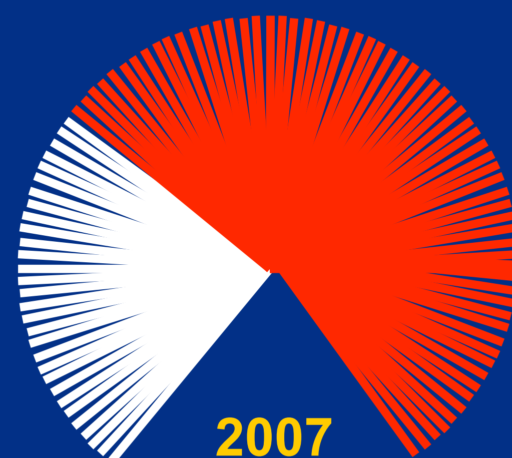
36 divisions: 24 cultured/ 12 candidate

Cultured

Uncultured

2003

53 divisions: 26 cultured/ 27 candidate



2007

~100 divisions: 30 cultured/ ~70 candidate

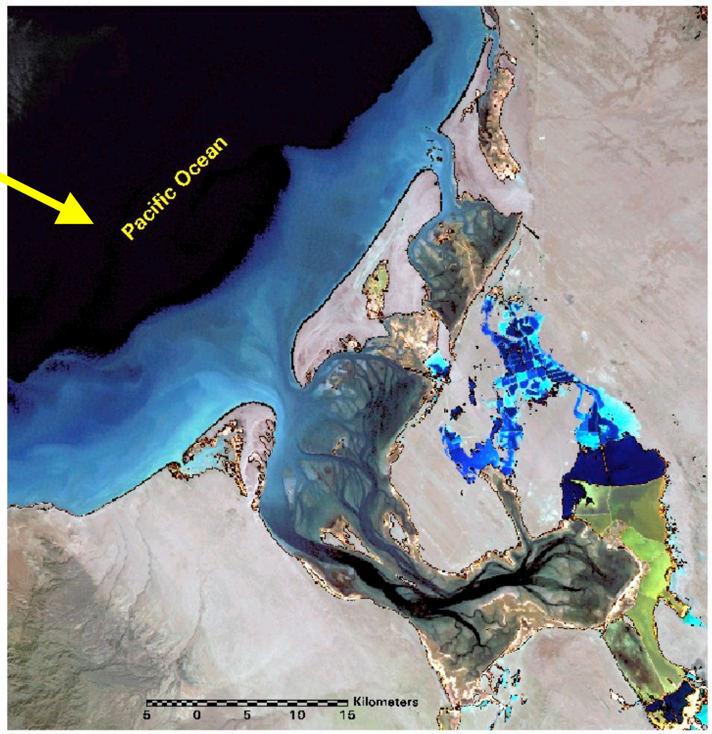
N.R. Pace

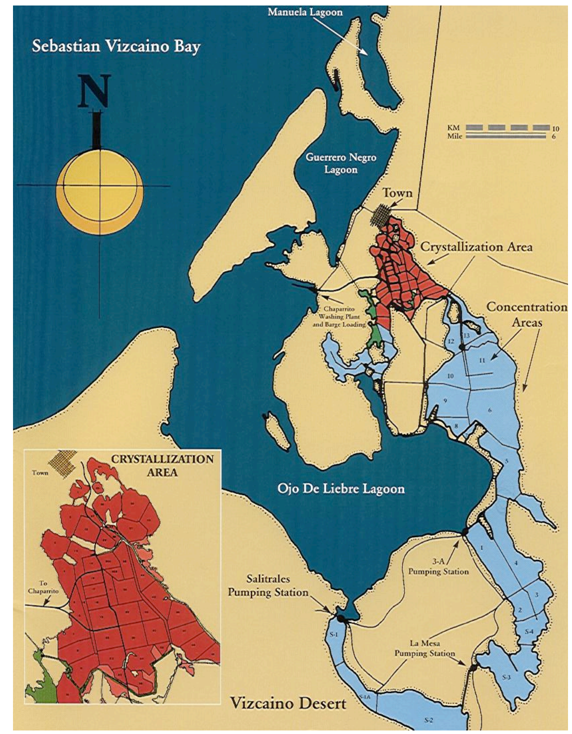
What chemistry are they doing out there in the natural world?

I.e., What to try to remotely sense?

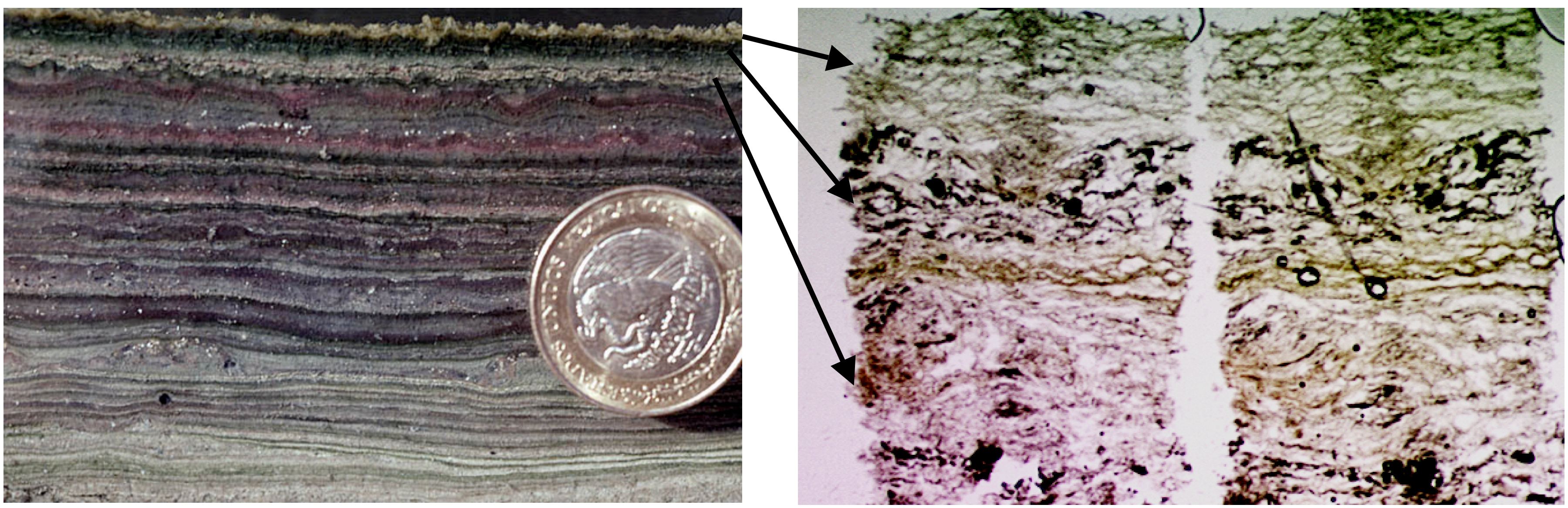
A potential study site that can be "ground truthed:" The Guerrero Negro hypersaline mat.

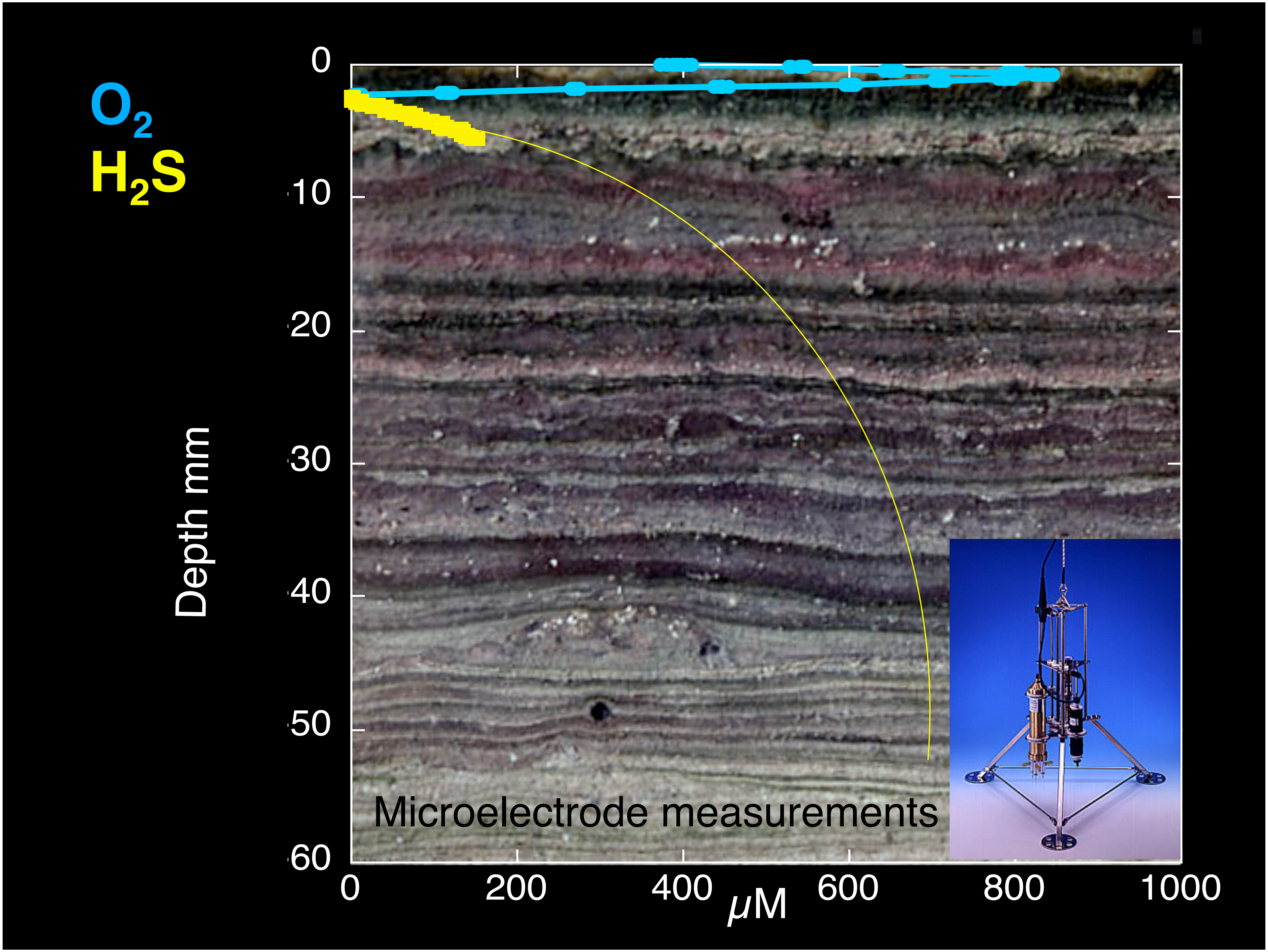
Exportadora de Sal
Guerrero Negro
Baja California Sur, Mexico



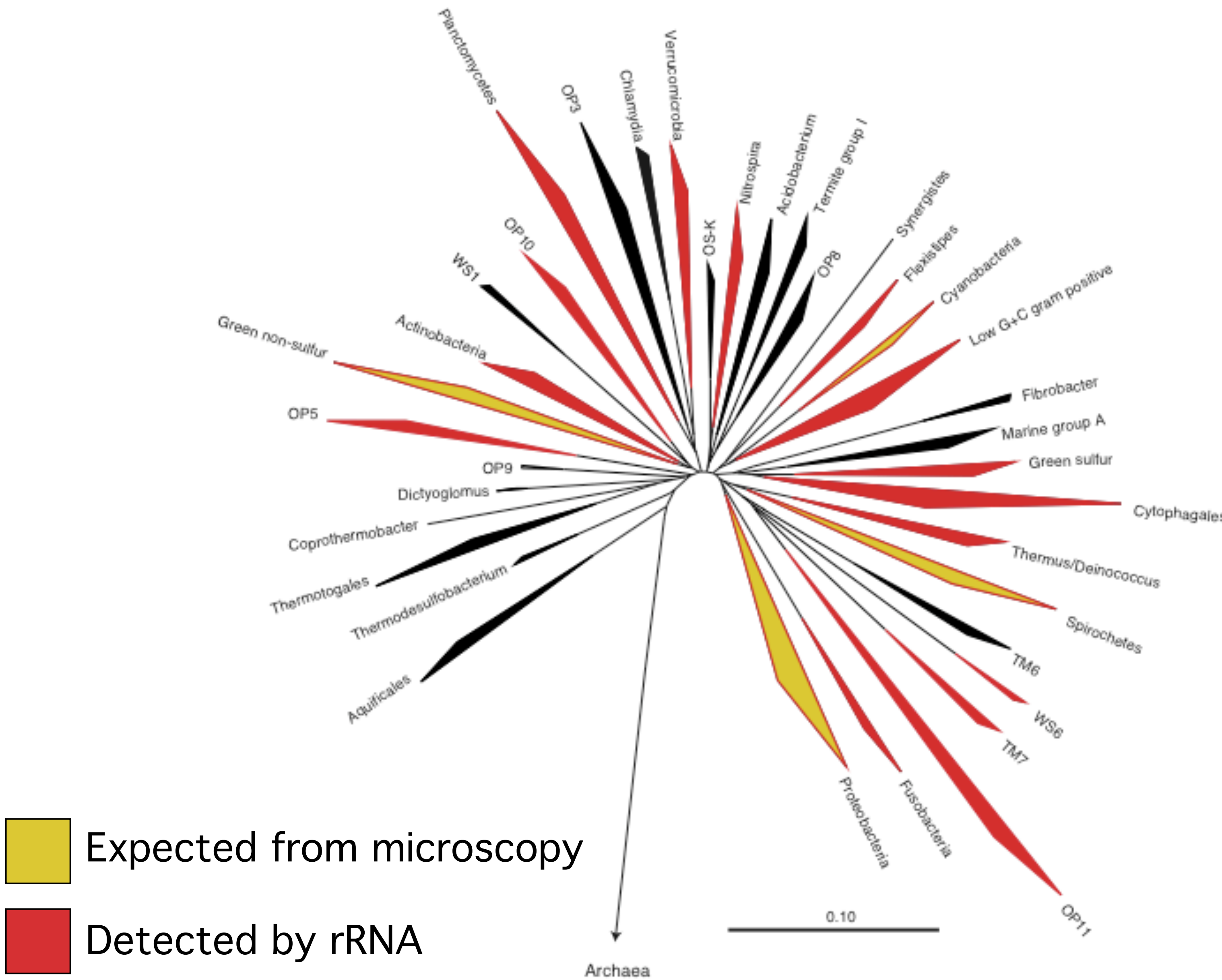


A microbial ecosystem





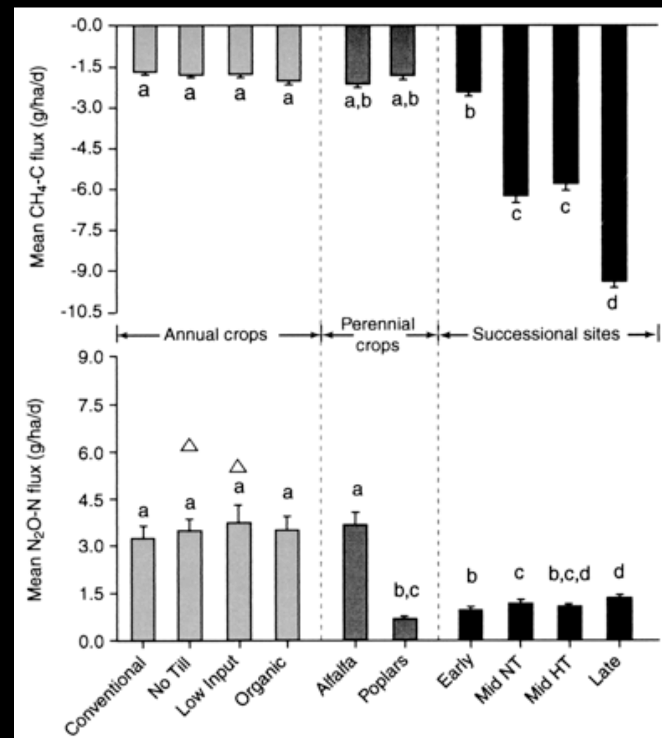
O_2
H_2S
Depth mm
0
10
20
30
40
50
60
0
200
400
600
800
1000
μM
Microelectrode measurements


Planctomycetes
OP3
Chlamydia
Verrucomicrobia
OS-K
Nitrospira
Acidobacterium
Termite group I
OP8
Synergistes
Flexistipes
Cyanobacteria
Low G+C gram positive
Fibrobacter
Marine group A
Green sulfur
Cytophagales
Thermus/Deinococcus
Spirochetes
TM6
WS6
TM7
OP11
Fusobacteria
Proteobacteria
Archaea
Aquificales
Thermodesulfobacterium
Thermotogales
Coprothermobacter
Dictyoglomus
OP9
OP5
Green non-sulfur
Actinobacteria
WS1
OP10
0.10
Expected from microscopy
Detected by rRNA

Microbial Diversity and Trace Gases

Tom Schmidt
Michigan State University

Kellogg Biological Station LTER



Robertson et al. (2000)
Science 289:1922

Contribution of soil to the global cycles of atmospheric trace gases

Trace Gas	Mixing ratio (ppbv)	Lifetime (days)	Total budget (Tg/yr)
H_2	550	1,000	90
CO	100	100	2,600
CH_4	1,700	4,000	540
OCS	0.5	1,500	2.3
N_2O	310	60,000	15
NO	<0.1	1	60
DMS	<0.1	<0.9	38
CH_3CCl_3	0.14	2,200	0.20
CF_2Cl_2	0.48	44,000	0.45

Conrad, Microbiological Reviews 60:609

LTER Network

http://www.lternet.edu

Tom Schmidt

tschmidt@msu.edu

Remote Sensing of Trace Gases

The Problem

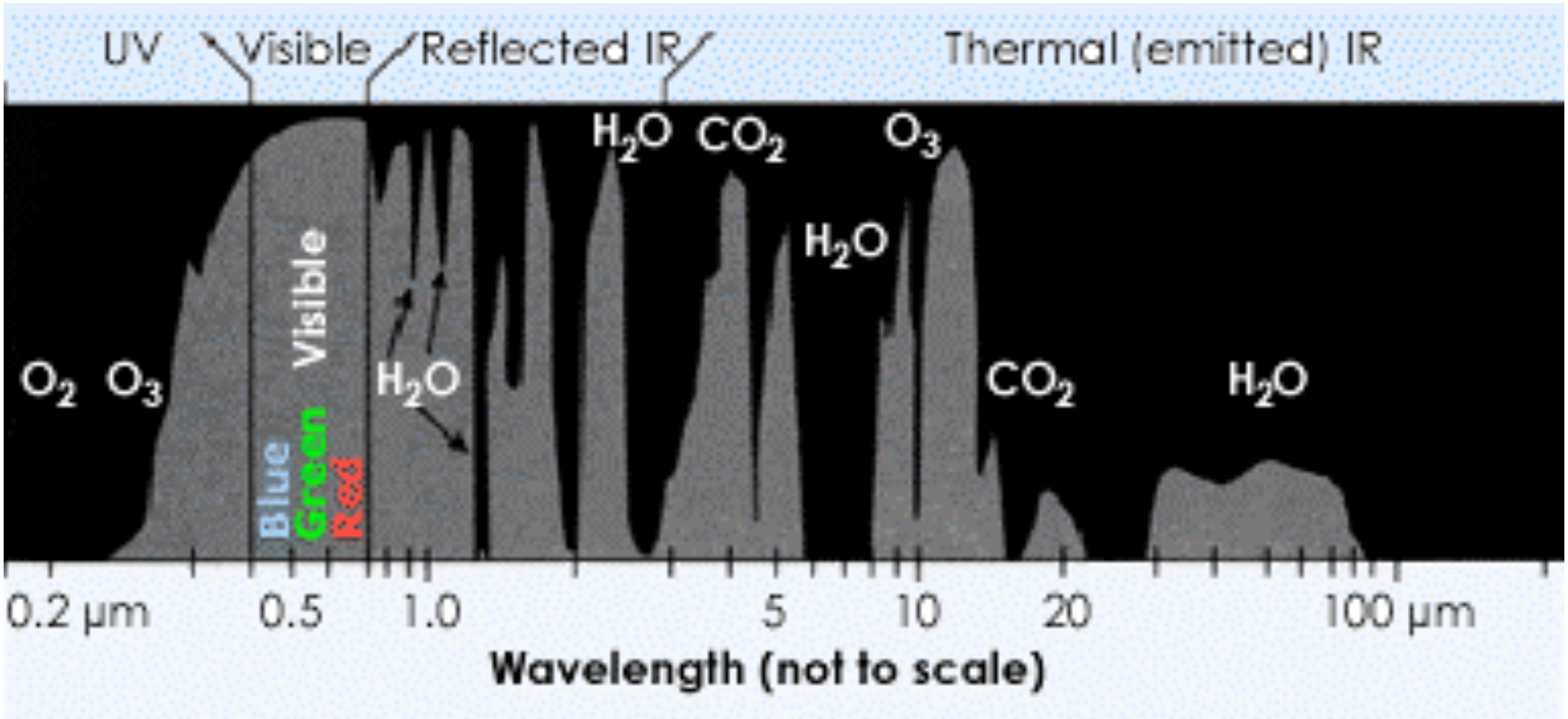
(& Several Solutions)

Michael J. Mumma

9 January 2008

Boulder, CO

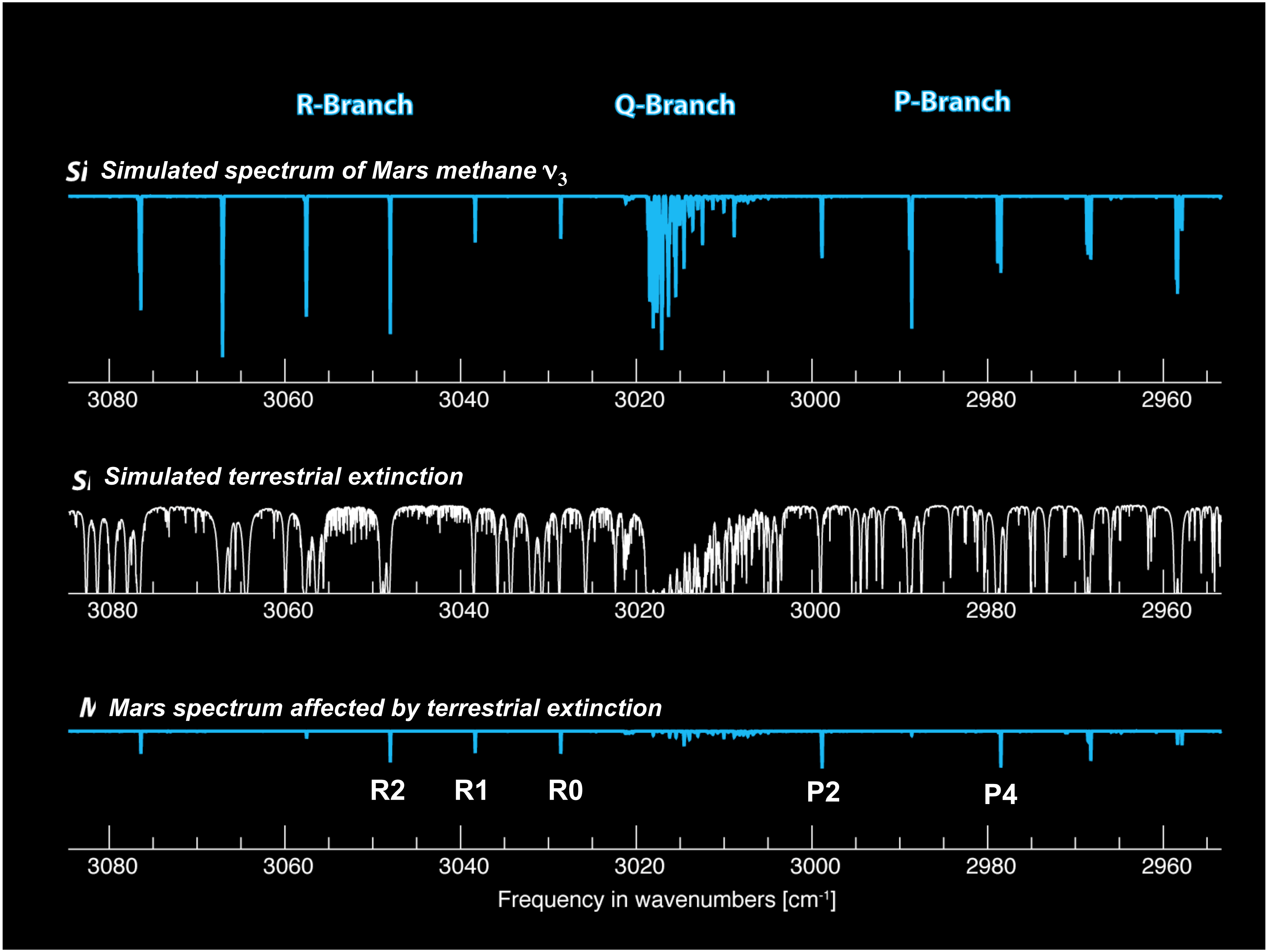
Optical Transmission of Earth's Atmosphere



50,000   10,000   3,300   1,000   500   100   50

Energy, cm^{-1}

300° K = 200 cm^{-1}



R-Branch
Q-Branch
P-Branch
Si Simulated spectrum of Mars methane ν3
3080
3060
3040
3020
3000
2980
2960
Si Simulated terrestrial extinction
3080
3060
3040
3020
3000
2980
2960
M Mars spectrum affected by terrestrial extinction
R2
R1
R0
P2
P4
3080
3060
3040
3020
3000
2980
2960
Frequency in wavenumbers [cm-1]

IR Hyperspectral Imager

Moderate spectral resolution ($\lambda/\delta\lambda$ ~ 80 and higher)

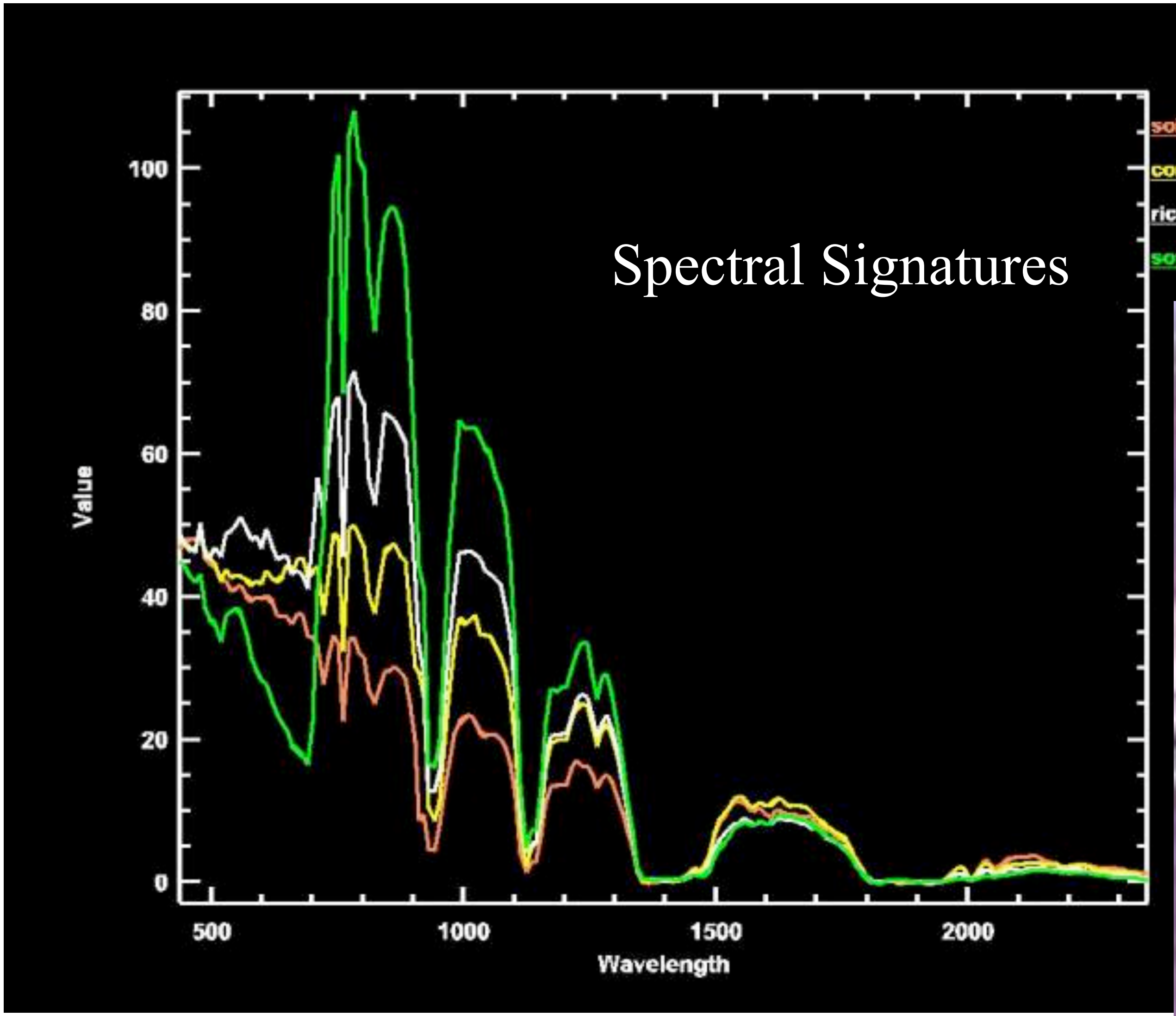
Spectrally complete

1024x1024 pixels

Science Applications of Hyperspectral Imager

- Atmosphere
  - Clouds/Aerosols
    - Fraction, Height, Reflectance
  - Major Constituents
    - CH_4, H_2O, CO_2
  - Trace Species
    - Industrial Effluent
- Land Surface
  - Vegetation
    - Type, Extent, Health
  - Fires and Thermal Activity
  - Localized Chemical Sources
  - Geology/Prospecting
  - Snow Age/Particle Size
- Water Surface
  - Ocean Currents, Ice Melting
  - Localized Chemical Sources

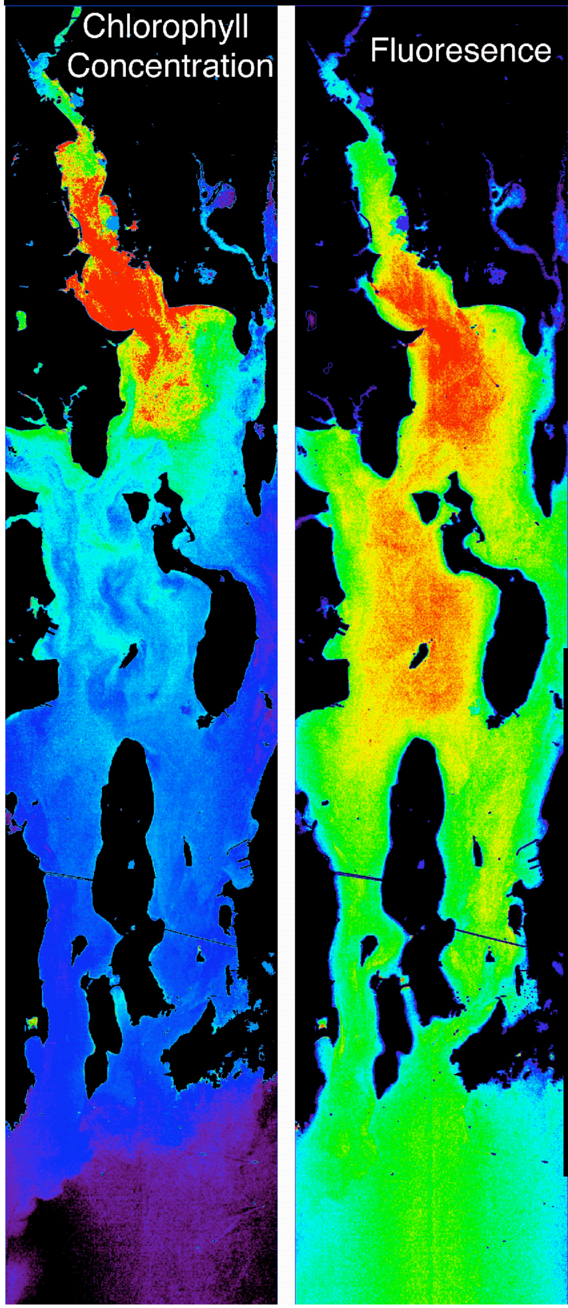
Hyperspectral Imaging can Differentiate Among Different Surface Vegetation Canopies

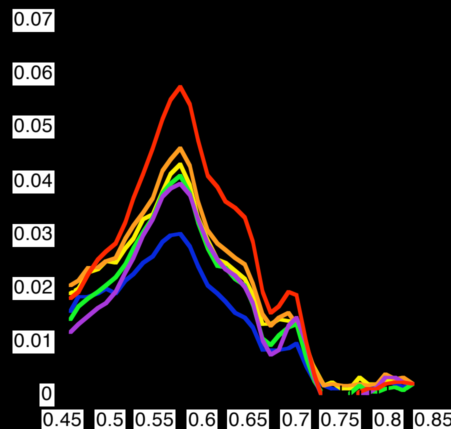


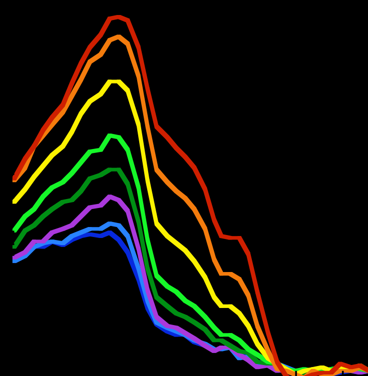
CSIRO

GEOLOGICAL SCIENCES
BROWN UNIVERSITY

Estuarine Remote Sensing: Optical Properties







Coastal zone, salt ponds, and their microbial diversity provide opportunities

Observations of water optical properties with field, airborne, and satellite hyperspectral systems can characterize chl a, colored dissolved organic matter, suspended sediment, bottom properties, and fluorescence

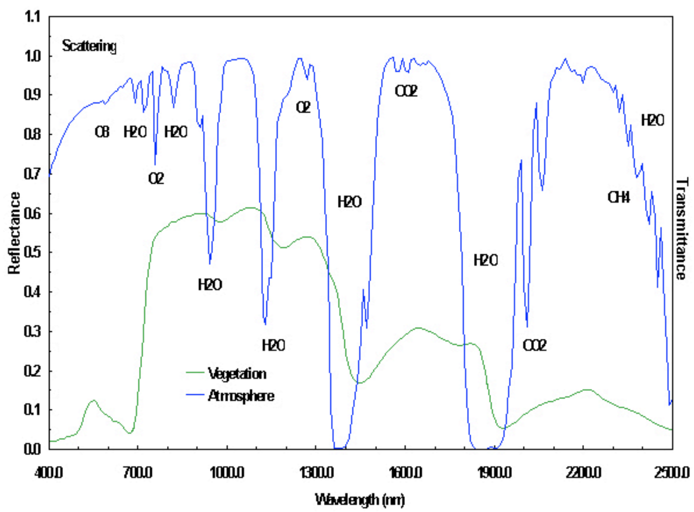
Fluorescence is a measure of phytoplankton activity and perhaps a measure of health

Tie in with long term, coarse resolution records to examine trends

Jack Mustard

Constituent Retrievals

- Water Vapor
  - 0.93 to 2.7 μm band daytime retrievals
  - 5 μm near surface diurnal
- 3.3 μm: CH_4 band retrievals
- 3 to 3.5 μm: Trace Hydrocarbons and Other Organics
- 4 to 5 μm: ds



Laser absorption spectroscopy

Ultra high spectral resolution ($\lambda/\delta\lambda \sim 1{,}000{,}000$)

Spectrally targeted

Swept or pulsed

Laser Remote Sensing of Trace Gases for Earth and Planetary Sciences

James B. Abshire*
Haris Riris, Graham Allan (Sigma), Xiaoli Sun, Michael Krainak
Mark Stephen, Kenji Numata (UMD), Anthony Yu, Emily Wilson

NASA-Goddard, Solar System Exploration Division

Presentation to:
NASA Astrobiology Institute's Workshop on Remote Sensing of Microbial Ecosystems
Boulder CO

January 9, 2008

* - James.Abshire@gsfc.nasa.gov

Why use tunable laser spectrometers for trace gas measurements ?

Drawbacks:

- Smaller spectral span width than passive spectrometers
- Have to fly a laser

Advantages:

- Continuous global coverage day & night, incl. dark polar regions
- Orders of magnitude better spatial resolution
- More accurate nadir-zenith path (simpler & fewer scattering errors)
- Higher Spectral resolution and selectivity:

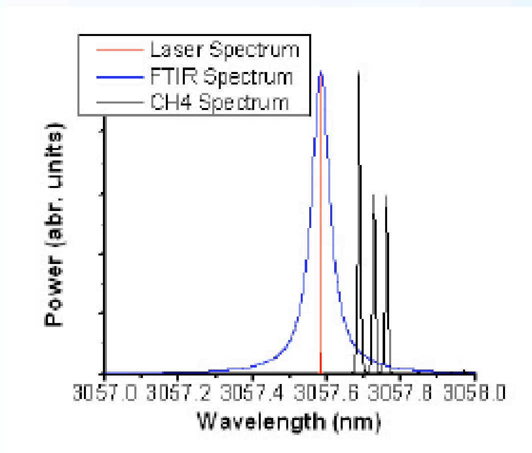


Figure 4a Comparison of measurement resolution - laser (red) and FTIR instrument (blue) spectral resolutions (0.03 cm^{-1}, or 900 MHz) plotted at the same scale with 3 lines of the CH4 absorption spectrum.

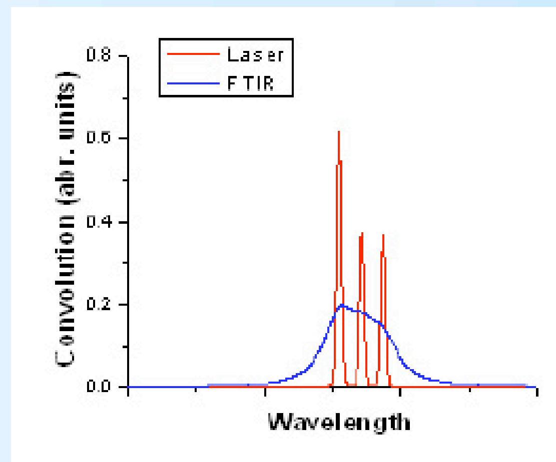
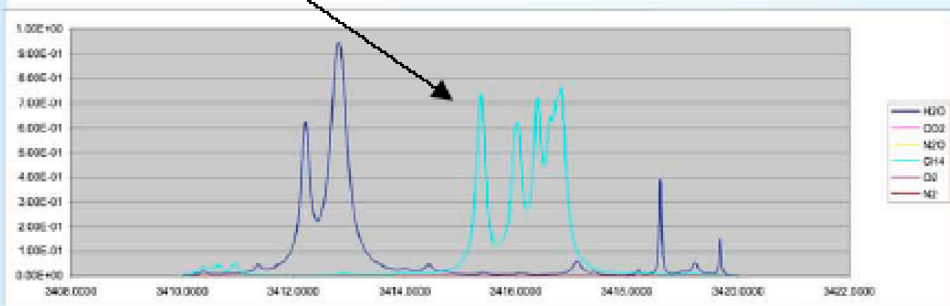


Figure 4b- Convolution of 3 lines in CH4 absorption spectrum with laser (red) and FTIR (blue) spectral resolutions plotted on the same scale. The narrower laser width (red) fully resolves the CH4 absorption s

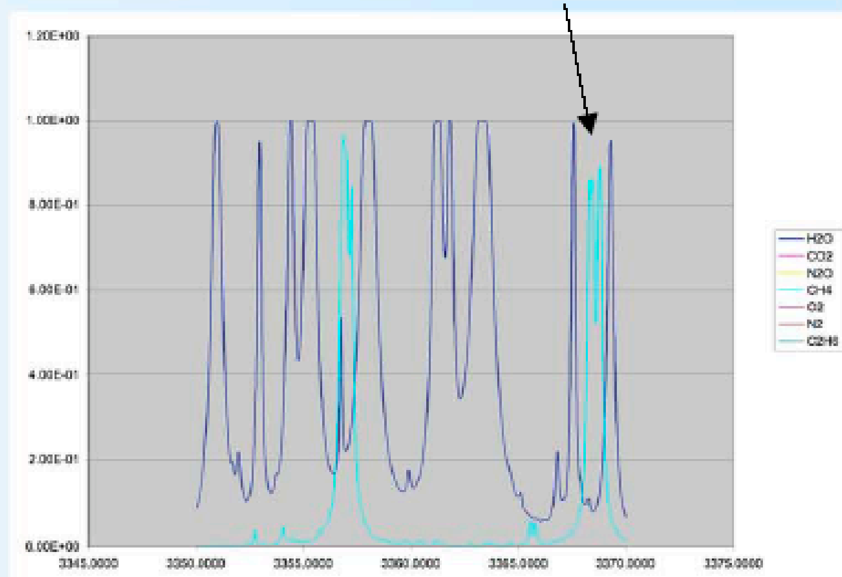
Quick calculations for measurements in Earth's Atmosphere (CH_4, H_2CO, C_2H_6 in presence of WV)

1 km path for Earth760 torr, 296 K

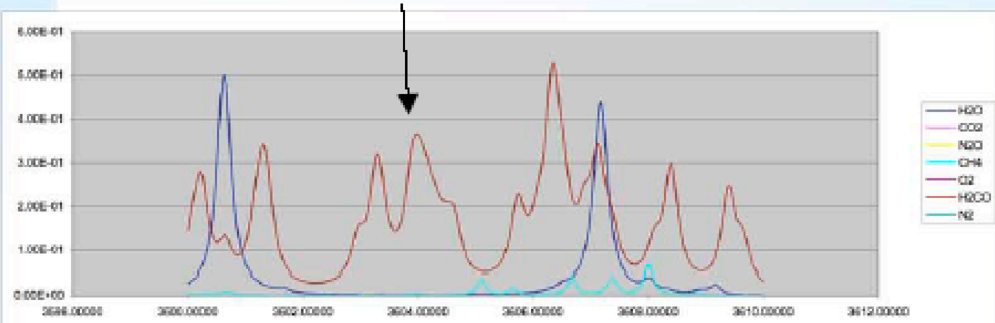
CH4 lines near 3416 nm (1.7 ppm)



C2H6 lines near 3365 nm (1ppm)



H2CO lines near 3604 nm (1 ppm)



Summary

- New capabilities:
  - "Laser sounder" technique allows sensitive path integrated measurements
    - Earth surface (land, water, vegetation) as target
    - "A frequency agile laser altimeter", but registers energy & gas line absorption
  - Fiber lasers - widely tunable; can access mid-IR via non-linear conversions
- Mid-IR:
  - Well suited for some trace gas measurements from Mars orbit
  - Looks promising for Earth, but must consider broader lines & interfering species
  - Sensitive detectors look promising (eg JWST)

A few questions:

- Most important gases ?
- Are gas ratios important ?
- Initial estimates of concentrations/abundances needed ?
- Are there "gas plumes" & if so dimensions ?
- Is this a "detection problem" or one to accurately measure abundances ?

What measurements are needed?

What search space must be covered?

Species

Wavelength range

Spatial resolution

Temporal coverage

Diurnal extent

Etc.